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Model of Cutting Force while Managing Two Regime Parameters in the Process of Internal Grinding

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Abstract

Methodology of optimization of grinding cycles for intragrinding operations requires a process model, establishing the connection between the cutting force occurring in the process of a metal removal and the regime parameters and other technological factors that have a significant impact on its intensity. Process management of internal grinding is carried out for a given cycle which simultaneously involves two controlling regime parameters: radial and axial infeeds actively changing in the process of grinding while the other operating parameters are constant during the entire grinding cycle. The developed model allows calculating the changes of the cutting force depending on variable values of infeeds. Fluctuation of infeeds values in each opening section is caused not only by the control program but also the kinematics of the internal grinding process. It should also be noted that the model of the cutting force provided in this article considers kinematics, peculiarities of the internal grinding and connects the cutting force with the processing regimes (radial and axial infeeds, number of billet and wheel revolutions) and main technological factors (physical mechanical properties of grinding metal, geometric parameters of a contact zone of the billet and the wheel, wheel characteristic, degree of blunting, etc.).

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1. Introduction

The cutting force is a major factor limiting the productivity of any operation performed on the machine tools including the internal grinding operations which are particularly susceptible to the value and fluctuations of the cutting force due to the low rigidity of the technological system in contrast to the circular outer grinding operations [1, 2]. In the production the intensity of metal removal during the internal grinding has to be reduced because of the need to reduce of the cutting force directly affecting the processing accuracy, value of thermal defects, surface roughness, blunting of the abrasive grains, the dimensional wear of the wheel, etc.

However the control of cutting force is carried out not directly but through a control program stepwise changing two regime parameters: the radial and axial infeeds during the cycle of the internal grinding. Therefore to control the cycle of the internal grinding the model of interrelations of the cutting force with radial and axial infeeds which takes into account the influence of the main technological factors including physical mechanical properties of grinding metal, geometric parameters of a contact zone of the billet and the wheel (actual speed of infeed, diameters of billet and wheel, rotational speed of billet, width of the processed surface of the billet), elastic properties of the technological system (yielding of the technological system), characteristics of an abrasive disk and blunting of the wheel grains must be worked out [3, 4].

Considering the wide range of processing conditions in the internal grinding operations, the empirical dependences should not be used as a model of the cutting forces. It is connected with the fact that the empirical dependences cover a narrow range of control factors, do not allow to establish the dependence between the basic technological parameters of the grinding process influencing the value of the cutting force and changing over a wide range in the terms of actual production [5, 6]. Thus, it requires the development of the model of the cutting force in the analytical form which is based on the fundamental regularities of plastic deformation mechanics of the metal in the cutting zone.

Nomenclature

P_Y, P_Z, P_X radial, tangential and axial resultant components of the cutting force, N
P_{YS}, P_{ZS}, P_{XS} radial, tangential, and axial components of the cutting force from the pressure of the plastic shear, N
P_{YTP} radial component of cutting force brought as a result of contact tensions action on the platform of grain blunting, N
P_{ZTP}, P_{XTP} components of tangential and axial cutting forces brought as a result of friction of the platform of grain blunting about the processing surface, N
P_{VS} component of resultant cutting force toward cutting velocity, N
β angle between direction of cutting velocity and resultant, deg
β_1 angle between grain velocity vector and shear plane, deg
φ angle between axial velocity of billet movement and cutting velocity, deg
η bluntness ratio of wheel
μ friction coefficient of abrasive grain by processed material
l_3 length of platform of grain blunting, mm
σ intensity of tensions, N/m^2
ε intensity of strain extent
Q intensity of metal removal, m^3/s
a section thickness by unit grain, mm
P_K average contact tension over the entire platform of friction at the time of metal cutting
f_p area of unit grain blunting platform
F total area of platforms of wheel cutting grain blunting, m^2
S_K geometric area of wheel and billet contact zone, m^2
S_{KYZ} geometric area of wheel and billet contact zone in the plane of action of radial and tangential cutting force, m^2

S_{KX}	geometric area of wheel and billet contact zone in the plane of action of axial cutting force, m^2
L	arc length of wheel and billet contact, m м
p	number of grains in the contact zone of wheel and part at the moment
c	coefficient establishing correlation between pressure intensity and contact tension
V_P	cutting velocity of abrasive grain of wheel grinding, m/s
V_{Soc}	velocity of axial infeed, m/s
V_{det}	rotational velocity of processed part, m/s
$V_{кр}$	rotational velocity of wheel, m/s
S_{rad}	radial infeed, mm/double-stroke
T	wheel height, m
d_{det}	interior diameter of billet, m
$D_{кр}$	wheel diameter, m

2. Simulation of the cutting forces by the example of internal grinding

To create the model of the cutting forces during the internal grinding, the operation of all components of cutting forces acting on a single grain of the grinding wheel in the direction of the cutting velocity vector need to be considered. The model developed by S.N. Korchak will be taken as the model of the interaction of the abrasive grain to the billet [7]. Total tangential and radial components of the cutting force by the single grain can be found by the formulas:

$$\begin{aligned} P_Y &= P_{YS} + P_{YTP} = \left(\frac{\sqrt{3,25}a \sin\beta}{\sin\beta_1} + 0,5l_3 \right) \cdot \frac{0,5\sigma}{\sqrt{3}} \\ P_Z &= P_{ZS} + P_{ZYTP} = \left(\frac{\sqrt{3,25}a \cos\beta}{\cos\beta_1} + 0,5\mu l_3 \right) \cdot \frac{0,5\sigma}{\sqrt{3}} \end{aligned} \qquad (1)$$

These formulas associate cutting forces with a shear section from the single grain but do not have complete connection with all regime parameters of the grinding process. In the work [8], power balance of the cutting forces for the single grain was obtained on the basis of a functional interrelation of the intensity of metal removal by grinding wheel with deformable elementary volume of the metal in the shearing zone:

$$\sigma\varepsilon Q = V_p \sum_{n=1}^{P} P_{VSn} \qquad (2)$$

Express the resultant cutting force in the direction of the cutting velocity through the radial, tangential and axial cutting forces:

$$P_{VS} = \frac{P_Y - P_{YTP}}{tg\beta} = \frac{P_Z - P_{ZTP}}{\cos\phi} = \frac{P_X - P_{XTP}}{\sin\phi} \qquad (3)$$

Taking into account the platforms of abrasive grain blunting components P_{YTP}, P_{ZTP}, P_{XTP} can be defined by dependences [7]:

$$\sum_{n=1}^{P} P_{YTPn} = \sum_{n=1}^{P} \overline{P}_{Kn} f_{pn} = P_K F$$
$$\sum_{n=1}^{P} P_{ZTPn} = \sum_{n=1}^{P} \overline{P_{Kn}} f_{Pn} \mu \cos\phi = P_K F \mu \cos\phi \tag{4}$$
$$\sum_{n=1}^{P} P_{XTPn} = \sum_{n=1}^{P} \overline{P_{Kn}} f_{Pn} \mu \sin\phi = P_K F \mu \sin\phi$$

We find the components of the cutting force substituting the appropriate resultant cutting force (3) and dependences (4) into the equation (2):

$$P_Y = \frac{Q\sigma\varepsilon tg\beta}{V_p} + P_K F$$
$$P_Z = \frac{Q\sigma\varepsilon\cos\phi}{V_p} + P_K F \mu \cos\phi \tag{5}$$
$$P_X = \frac{Q\sigma\varepsilon\sin\phi}{V_p} + P_K F \mu \sin\phi$$

The total area of the contact platforms of blunting of the cutting wheel grains located in the contact area of the wheel with the billet can be found as a product of the geometric area of the wheel and billet contact on the degree of wheel bluntness. In the plane of action of the radial and tangential cutting forces the geometric wheel area of the contact zone of the wheel and billet can be determined by formula (6) [9].

$$S_{K_{Y,Z}} = LT = T\sqrt{\frac{dDS_{rad}}{d-D}} \tag{6}$$

Average contact tension under the platform of bluntness depending on the tension intensity is determined by the formula [10]:

$$P_K = \frac{\sigma}{c} = \frac{\sigma}{3} \tag{7}$$

According to the source [10] the value of coefficient determining correlations between the tension intensity and the contact pressure equals 3. Removal rate is the volume of metal removable by the grinding wheel per unit time and it can be calculated by the formula [11]:

$$Q = \pi d V_{Soc} S_{rad} \tag{8}$$

The cutting speed of the abrasive grain of the grinding wheel can be determined by the formula:

$$V_p = \sqrt{(V_{\kappa p} + V_{\det})^2 + V_{Soc}^2} \tag{9}$$

In the work [10] the mean value of the intensity of the deformation degree ($\varepsilon_i \approx 2,732$) and the average value of the angle between the direction of the cutting velocity and the resultant force at cutting of sharp grain ($\beta \approx 34^\circ 18'$) were obtained.

Substituting dependences (6), (7), (8) and (9) in the equation (5) we obtain the model of the cutting force as the following complex of formulas for the calculation of the cutting forces components for the internal grinding.

$$P_Y = \frac{1{,}86\sigma\pi d V_{Soc} S_{рад}}{\sqrt{\left(V_{кр} + V_{\det}\right)^2 + V_{Soc}^2}} + \frac{\sigma\eta T}{3}\sqrt{\frac{dDS_{rad}}{d-D}} \qquad (10)$$

$$P_Z = \frac{2{,}732\sigma V_{\det}\pi d V_{Soc} S_{rad}}{(V_{кр} + V_{\det})^2 + V_{Soc}^2} + \frac{\sigma\eta\mu V_{\det} T}{3\sqrt{(V_{кр} + V_{\det})^2 + V_{Soc}^2}}\sqrt{\frac{dDS_{rad}}{d-D}} \qquad (11)$$

$$P_X = \frac{2{,}732\sigma\pi d V_{Soc}^2 S_{rad}}{(V_{кр} + V_{\det})^2 + V_{Soc}^2} + \frac{\sigma\eta\mu V_{Soc} S_{K_X}}{3\sqrt{(V_{кр} + V_{\det})^2 + V_{Soc}^2}} \qquad (12)$$

3. Conclusion

The cutting force model for internal grinding (formulas 10-12) developed on the basis of the fundamental regularities of plastic deformation mechanics in the cutting area

- takes into account the kinematics and peculiarities of the internal grinding process;
- connects the cutting forces with processing regimes (radial and axial infeeds, rotational speed of billet and wheel, etc.);
- covers most of the main technological parameters (physical mechanical properties of polished metal, geometrical parameters of the wheel and billet contact zone, wheel characteristics, the degree of blunting, etc);
- is used in the models of metal removal process and in the models of regime parameters restrictions while optimizing processing intragrinding cycles in a multidimensional space of control parameters [12-16].

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